N82 17019 D5

A SUMMARY OF RESULTS FROM SOLAR MONITORING ROCKET FLIGHTS

Charles H. Duncan
Goddard Space Flight Center

ABSTRACT

Three rocket flights to measure the solar constant and provide calibration data for sensors aboard Nimbus 6, 7, and Solar Maximum Mission (SMM) spacecraft have been accomplished. The values obtained by the rocket instruments for the solar constant in SI units are: 1367 wm^{-2} on 29 June 1976; 1372 wm^{-2} on 16 November 1978; and 1374 wm^{-2} on 22 May 1980. The uncertainty of the rocket measurements is ±0.5%. The values obtained by the Hickey-Frieden (H-F) sensor on Nimbus 7 during the second and third flights was 1376 wm^{-2}. The value obtained by the Active Cavity Radiometer Model IV (ACR IV) on SMM during the flight was 1368 wm^{-2}.

INTRODUCTION

Three rocket flights to measure the solar constant and provide "ground truth" calibrations for spacecraft sensors have been accomplished to date. The first flight was initiated by NASA Headquarters in January 1976 because the values being obtained for the solar constant by the ERB flat-plate detector on Nimbus-6 were 1.5 percent higher than expected, i.e., 1392 wm^{-2}. Nimbus-6 first began taking data on July 2, 1975. This first flight identified a calibration error of +1.6 percent in the Nimbus-6 ERB channel 3 values. Subsequently, Hickey, et al., have identified the cause for +0.7 percent of this calibration error. The reasons for the remaining +0.9 percent error has not been identified to date. However, Hickey only claimed ±0.75 percent accuracy for this detector[1], so the values obtained from both spacecraft and rocket during the first flight are within the bounds of uncertainty of ±0.5 percent.[2] This paper provides some background on the history and results of these rocket flights.

FIRST ROCKET FLIGHT

Prior to authorizing the first rocket flight, NASA HQ convened an Ad Hoc Science Review Committee to consider the merits, probability of success and selection of experiment payload. The committee met initially on January 26, 1976. The personnel were:

Guenther Brueckner	–	Naval Research Laboratory, Washington, DC
Louis Drummeter	–	Naval Research Laboratory, Washington, DC
John Gille	–	National Center for Atmospheric Research, Boulder, CO
Verner Suomi	–	University of Wisconsin, Madison, WI

Robert Madden — National Bureau of Standards, Washington, DC
Jon Geist — National Bureau of Standards, Washington, DC

This committee made the following recommendations:

1. Ground intercomparisons at a high mountain site among rocket payload and neutral outside sensor [recommended PMO (Physikalisch-Meteorologisches Observatorium) Davos, Switzerland sensor developed by C. Fröhlich] be conducted prior to flight under ambient and vacuum conditions (10^{-4} Torr) and that agreement among all instruments be better than ±0.5 percent.

2. Tests to be conducted to verify behavior of payload upon exposure to the pressure temperature profile of the mission using thermal vacuum chambers and a solar simulator. Any effects upon performance to be noted and mission aborted if these effects cause more than 0.1 percent changes in response of individual instruments.

3. To minimize thermal problems and to eliminate all windows, payload to be launched in an evacuated configuration (10^{-4} Torr).

4. Instrument payload to consist of prototypes of ERB solar channels and as many self-calibrating radiometers as possible.

Subsequent to this meeting and prior to the flight, a final review of the results of intercomparisons, pressure-temperature profile testing, and related factors was held at NASA HQ on June 3, 1976. Upon presentation of the data, the Ad Hoc Committee gave its final approval for flight.

Pertinent test results presented at this meeting included:

1. Ratios of irradiance by the five payload instruments were shown to be constant at all irradiance levels at all pressures.

2. Calibration factors for pressure intermediate between 50 Torr and 10^{-4} Torr for ERB 3, ESP, and PACRAD were derived.

3. Simulation of launch pressure variations showed that all five instruments would read the solar constant within less than 45 seconds after first acquisition of the sun.

4. The five solar constant detectors (rocket payload plus two PMO detectors) agreed with each other within ±0.3% during the South Baldy intercomparisons at both ambient and vacuum (10^{-4} Torr).

5. An insect was trapped in canister upon placement of quartz window on payload at South Baldy and subsequently fell into the receiver of the PACRAD causing a 2.83 percent decrease in measurement data. Quartz was removed, bug was removed, PACRAD re-exposed to sun and obtained original results as compared to other instruments.

6. Payload instruments viewed LN_2 target (-185°C) at 10^{-6} Torr to determine zero offset.

Table I lists the instruments and investigators for each of the rocket flights. The first flight was launched on June 29, 1976 at 12:20 PM MDT from White Sands, New Mexico. During launch, according to readings obtained by the ERB-3 sensor (fast time constant, pressure sensitive) the canister lost vacuum during the initial launch phase and did not recover until the nose cone was blown. This fact was also verified by the PACRAD. The ACR IV, not having demonstrated pressure sensitivity during five track tests, did not note this fact.

The initial values reported by the investigators at about 3 minutes into flight did not change by more than 1 wm^{-2} except for the ERB-3 value which was initially reported as 1374 wm^{-2} and subsequently changed to 1389 wm^{-2}. The justification being: ERB on Nimbus-6 when pointed to

TABLE I. SOLAR MONITORING ROCKET FLIGHTS

- PAYLOAD FOR 1ST FLIGHT

INSTRUMENT	INVESTIGATOR/ INSTITUTION	SUPPORT CONTRACTOR
ACR IV 402A ACR IV 402B	R. C. Willson/JPL	TRW, Los Angeles, CA[1]
PACRAD	J. Kendall/JPL R. Harrison/JPL	None
ERB-ESP Channels 2 3 4 5 of Nimbus-6 ERB	J. Hickey/Eppley	Gulton Industries,[1] Albuquerque, NM

- CHANGES FOR 2ND AND 3RD FLIGHTS

  – ERB-ESP – Eliminate Channels 2, 4, and 5
  – Add Channel 3 With Anodized Baffles
  – Add H-F Sensor

10/27/80

[1]For Flights 1 and 2 only; no support contractors for third flight.

space produced a negative count equal to 15 wm^{-2}. If this negative offset were applied to the rocket data then 1374 +15 = 1389 wm^{-2} which made perfect agreement between rocket 1 and Nimbus-6 ERB. Table II lists the values obtained by the rocket instruments and Nimbus 6 ERB.

SECOND ROCKET FLIGHT

The program lay dormant from the first flight on June 29, 1976, until October 27, 1977, when an AN proposal was accepted for four additional rocket flights to be conducted under the general philosophy developed by the Ad Hoc Science Review Committee.

The payload was refurbished; Hickey substituted an ERB-3 channel with anodized baffles and an improved version of the ESP, termed an H-F, for the filter solar channels flown on the first flight. These channels did not obtain any data which gave meaningful insight into the behavior of the same channels on Nimbus-6 ERB. Each of these channels was covered with a filter and some values were higher and some lower on the rocket as compared to the spacecraft with differences of 27 wm^{-2}, 20 wm^{-2}, and 1 wm^{-2} noted.

The addition of the ERB-3 with anodized channels was added to try to identify the source of the calibration error of Nimbus-6 ERB discovered by the first rocket flight. The H-F sensor was added because it had become part of the payload of Nimbus-7 as channel 10 C.

The intercomparison of the Nimbus-7 channel 10 C detector with the rocket payload prior to the launch of Nimbus-7 could not be accomplished. Subsequently, the second rocket flight was launched on the same day and obtained values at the same time as the Nimbus-7 ERB was first turned on. Also, during the second flight, the payload was pointed off sun for 30 seconds to try to verify that the space offset of ERB-3 was really 15 wm^{-2}. The payload also lost vacuum about 15 minutes prior to launch.

The primary result from the second flight was an apparent increase in the solar constant since the first flight. The result of off sun pointing was inconclusive since the ERB detector first began exhibiting negative counts, then reversed this trend, then became negative again for a few seconds, then acquired the sun. This effect was most probably due to the fact that the nose cone was drifting into and out of the field of view of the instrument. The negative offset maximum observed was equivalent to approximately 12 wm^{-2}. This verifies that the space offset observed for Nimbus 6 was most probably the same for the rocket although sufficient observation time was not available to reach 15 wm^{-2}. It should be noted that: according to Hickey[1] "The space look offset amounts to almost 0.9 percent of the solar constant value for ERB channel 3."

The most disappointing aspects of this flight were the saturation of the H-F sensor in flight due to the wrong value of heater power being set, the saturation of the ACR IV-B, and the initial low values, 2-3 percent lower than expected, obtained by the FSP. The FSP lower values were later

[1] Private communication.

TABLE II. SOLAR MONITORING ROCKET FLIGHTS

Results of 1st Flight – June 29, 1976 @ 12:20 PM MDT – White Sands, NM

INSTRUMENT	VALUE
PACRAD	1364 wm^{-2}
ACR A	1368 wm^{-2}
ACR B	1368 wm^{-2}
ESP	1369 wm^{-2}
Mean	1367 wm^{-2}
ERB Rocket Channel 3	1389 wm^{-2}
ERB Nimbus Channel 3	1389 wm^{-2}
Difference ERB Channel 3 and Rocket Payload Mean	+22 wm^{-2} or +1.6%

10/28/80

found to be due to aperture contamination and a change in the parameters relating back heater power to irradiance. A recharacterization of the ERB sensors accomplished during this activity discovered a +0.7% calibration error for the Nimbus-6 ERB sensors as flown on Nimbus-6 and the first rocket flight. The anodized baffles on ERB-3 gave the same results as the painted baffles so this channel yielded no new information to resolve the calibration anomaly noted on the first flight. Table III lists the values for this flight along with the Nimbus 6 & 7 ERB values. The values shown for the ESP include the convection of 1.96% for aperture contamination and 0.3% for heater power parameter changes. Both values are shown.

Because of the importance of the possible increase in the solar constant, a post-flight intercomparison was held at Table Mountain, California, on 10-13 December 1978. Hickey was unable to participate in this intercomparison. However, Fröhlich of WMO and Crommelynck of Belgium both participated. Crommelynck has been selected to fly a solar constant experiment aboard the shuttle and brought his prototype for this flight to Table Mountain. Fröhlich brought with him the same instruments which had initially been used at the South Baldy intercomparisons. The results of this intercomparison were that the PMO and ACR IV-A were still reading within 0.06 percent of the intercomparison values at South Baldy while the PACRAD was reading 0.5 percent higher. Kendall and Harrison reported subsequently[2] that an incorrect characterization had been used in the South Baldy intercomparisons, but the correct characterization had been used for both the first and second rocket flights and for the post-flight intercomparisons, after the second rocket flight. They maintained that their instrument had truly shown an increase in the solar constant between the two flights.

During this time period, Willson intercompared his three sensors flown on the SMM with the rocket ACR IV instruments. In comparison to the rocket ACR IV-A, the SMM sensors A, B, and C read 0.2 percent, 0.04 percent, and 0.3 percent higher respectively. The Crommelynck sensor read 0.7 percent lower, the PMO2 read 0.5 percent lower and the PMO6 read 0.15% lower than the ACR 402A.

The value derived from the second rocket flight for the solar constant of 1372 wm^{-2} was 4 wm^{-2} lower than the value obtained simultaneously by Nimbus-7 channel 10 C (H-F). However, the rocket instruments were not intercompared with the Nimbus-7 channel 10 C before launch of Nimbus 7 so the bias between the rocket instruments and the H-F could not be identified since the rocket H-F saturated. These two values were within the uncertainty of the measurements however.

THIRD ROCKET F 'IT

As a result of the values obtained from the second flight, the investigators (Willson, Hickey, Kendall, Harrison) took extreme care in the preparation and execution of the third flight.

Extensive intercomparisons before the flight were made on 15-19 April 1980. During this intercomparison, the relative performance of the rocket sensors was established again. The

[2] Private communication.

TABLE III. SOLAR MONITORING ROCKET FLIGHTS

Results of 2nd Flight – November 16, 1978 @ 11:15 MST – White Sands, NM

INSTRUMENT	VALUE
PACRAD	1371 wm^{-2}
ACR A	1373 wm^{-2}
ACR B	Saturated
ESP	1373 wm^{-2}* – 1378 wm^{-2}
H-F	Saturated
Mean (No-ESP)	137[illegible] wm^{-2}
Mean (With-ESP)	1372–1374 wm^{-2}
ERB Rocket Channel 3	1383 wm^{-2}
ERB Nimbus-6 Channel 3	1387 wm^{-2}
ERB Nimbus-7 Channel 3	1383 wm^{-2}
Mean	1384 wm^{-2}
Nimbus-7 H-F Channel 10C	1376 wm^{-2}
Difference ERB Channels 3 and Rocket Payload Mean	+12 wm^{-2} or +0.9%
Difference H-F Channel 10C and Rocket Payload Mean	+4 wm^{-2} or +0.3%

*Value derived after disassembly of sensor.

PACRAD and ACR IV were consistent with their performance during the initial intercomparisons at South Baldy peak. The ESP read about 0.3% higher than during the intercomparisons before the first flight. The H-F which had never been intercompared previously read about the same as the PACRAD; about 0.3 percent lower than the ACR's, and about 0.8 percent lower than the ESP.

The decision was made prior to the third rocket flight not to try to evacuate the canister since vacuum had not been maintained after launch for either of the two previous flights and the effects of dynamic heating were negligible on causing temperature excursions on the instruments.

Consequently, the payload was purged with dry air for a week before launch whenever possible and continuously until launch after the horizontal test was complete, a period of about 48 hours.

The third flight had been scheduled to coincide with the first turn-on of SMM ACRIM. Problems with the Aerobee 170 rockets forced a delay of the flight to May 22, 1980 after a decision had been made to fly the payload aboard an Astrobee rocket instead of continuing to wait for an Aerobee 170 to be readied.

The results from the third flight agree very closely with those from the second flight for both rocket instruments and Nimbus-7 H-F measurements. The results are summarized in Table IV. Nimbus-7 channel 10 C measured 1376 wm^{-2} for the dates of each of these flights and the rocket averages for the second and third flights were 1372 and 1374 wm^{-2} respectively, all well within the estimated uncertainty of the instruments.

However, the SMM ACRIM was also in space on 22 May 1980 obtaining a value of 1368 wm^{-2} for the solar constant. These ACRIM instruments (now reading lower in space) had read about 0.2 percent higher than the rocket ACR IV's during intercomparisons at Table Mountain in December 1979. This result indicated that environment, possibly pressure, might influence the measurements of the ACR detectors. Also, the H-F during intercomparisons in April 1980 at Table Mountain read 0.3 percent lower than the rocket ACR but during the third rocket fligh., it read 0.3 percent higher for a total difference of 0.6 percent. The rocket H-F, however still read about 0.2 percent higher than the Nimbus-7 H-F for a total difference between ground intercomparisons and spacecraft values of about 0.4 percent which is very close to the difference (0.6%) observed by Willson between ground, rocket, and space performance.

SUMMARY

Table V lists pertinent data for each of the three flights along with sunspot numbers on the dates of the flights. Table VI summarizes the results of the measurements for the three flights. Table VII summarizes the results from Nimbus 6 & 7 ERB and SMM ACRIM for the dates of the flights. Table VIII presents an average value for the solar constant for the dates of each flight using both rocket and spacecraft data. The rocket average value for the solar constant is given equal value to the spacecraft values in a simple arithmetical average.

TABLE IV. SOLAR MONITORING ROCKET FLIGHTS

Results of 3rd Flight – May 22, 1980 @ 9:00 MDT – White Sands, NM

INSTRUMENT	VALUE
PACRAD	1373 wm^{-2}
ACR A	1373 wm^{-2}
ACR B	1374 wm^{-2}
H-F	1378 wm^{-2}
ESP	1385 wm^{-2}
Mean	1377 wm^{-2}
ERB Rocket Channel 3	1377 wm^{-2}
ERB Nimbus-6 Channel 3	1377 wm^{-2}
ERB Nimbus-7 Channel 3	1367 wm^{-2}
Mean	1374 wm^{-2}
Nimbus 7 H-F Channel 10C	1376 wm^{-2}
SMM ACRIM A, B, C Average	1368 wm^{-2}
Difference ERB Channels 3 and Rocket Payload Mean	3 wm^{-2} or 0.2%
Difference H-F Channel 10C and Rocket Payload Mean	1 wm^{-2} or 0.07%
Difference SMM ACRIM and Rocket Payload Mean	9 wm^{-2} or 0.6%

TABLE V. DATA RELATIVE TO ROCKET FLIGHTS

Date	Time of Launch	Peak Altitude	Length of Obs. Int'v.	Start of Meas'mt. Int'v.	Zurich SS Number	Ottawa 2808 MHz Flux	Bartels 27 Day Cycle No.
29 June 76	1220 MDT	255 km @ +247 sec.	311 sec.	+ 93 sec.	11	71.3	7
16 Nov. 78	1115 MST	183 km @ +222 sec.	212 sec.	+133 sec.	77	128.8	13
22 May 80	0900 MDT	249 km @ +260 sec.	339 sec.	+ 94 sec.	244	276.6	26

TABLE VI. VALUES OF THE SOLAR CONSTANT FROM ROCKET FLIGHTS

(All Values in wm^{-2})

Date	ACRA	ACRB	PACRAD	ESP	H-F	ERB-3 Painted	ERB-3 Anodized	Average Value
29 June 76	1367	1368	1364	1369	[3]	1380	[3]	1367
16 Nov. 68	1373	[1]	1371	1373 – 1378 [2]	[1]	1383	1381	1372
22 May 80	1373	1374	1373	1385	1378	1377	1374	1374 [4]

Notes:
[1] Saturated during flight.
[2] See text for explanation.
[3] Not flown on this flight.
[4] ESP not included in average value.

TABLE VII. SPACECRAFT SOLAR CONSTANT VALUES AND SUNSPOT NUMBERS FOR DATES OF ROCKET FLIGHTS

Date	Zurich Sunspot Number	Nimbus-6 (ERB-3) Channel 3	Nimbus-7 (ERB-3) Channel 3	Nimbus-7 Channel 10-C (H-F)	SMM (ACR) ACRIM	Mean of Rocket Values
29 June 76	11	1389	N.A.	N.A.	N.A.	1367
16 Nov. 78	77	1387	1383	1376	N.A.	1372
22 May 80	244 (provisional)	1377	1367	1376	1368	1374

TABLE VIII. AVERAGE VALUE OF SOLAR CONSTANT AT TIMES OF ROCKET FLIGHTS (CAVITY SENSORS IN SPACE)

Date	Sensors	Value (wm^{-2})	Average Value (wm^{-2})
29 June 1976	Rocket Payload	(1367)	1367
16 Nov. 1978	Rocket Payload	(1372)	1374
	Nimbus 7 H-F	(1376)	
22 May 1980	Rocket Payload	(1374)	1373
	Nimbus 7 H-F	(1376)	
	SMM ACRIM	(1368)	

A fourth rocket flight is planned for May 1981. The experiment canister is being rebuilt so that vacuum can be maintained prior to and after launch. Fröhlich will also provide two PMO-6 sensors for the experiment payload under an international agreement which has been negotiated recently. Plans for this flight also include 30 seconds off sun pointing after 5 minutes of data have been taken to establish the space offset values for the sensors.

REFERENCES

1. J. R. Hickey and A. R. Karoli, Appl. Opts., 13, 523 (1974).

2. C. H. Duncan et al., Appl. Opts., 16, 2690 (1977).